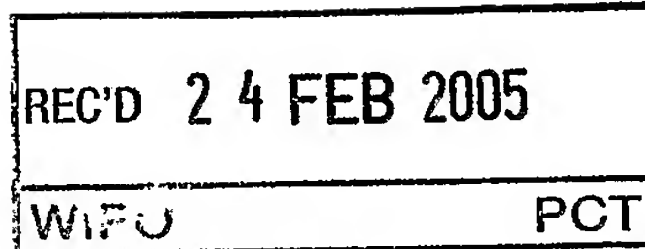


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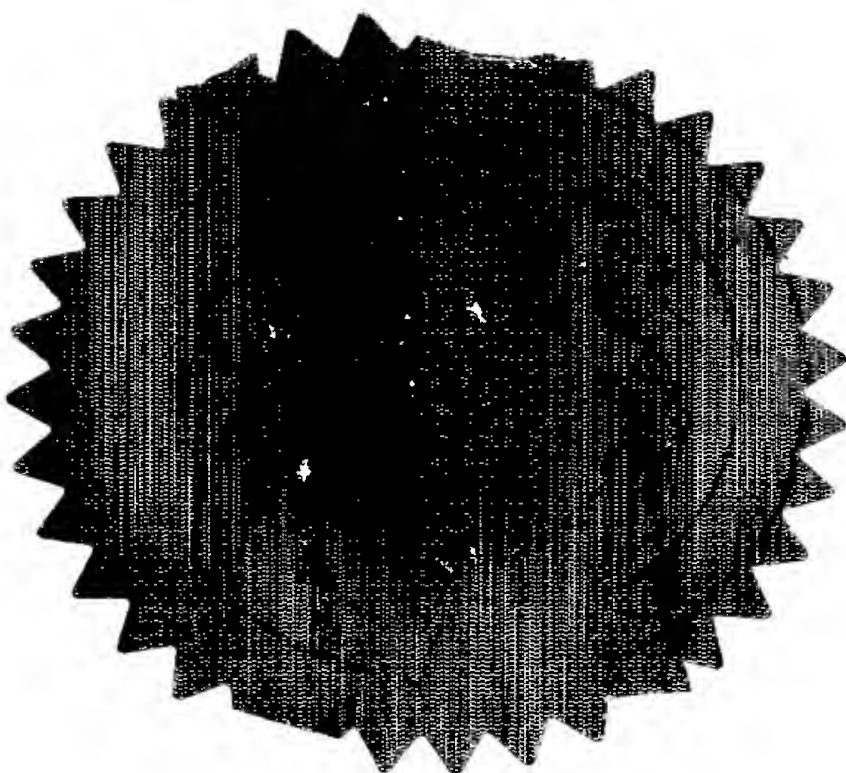


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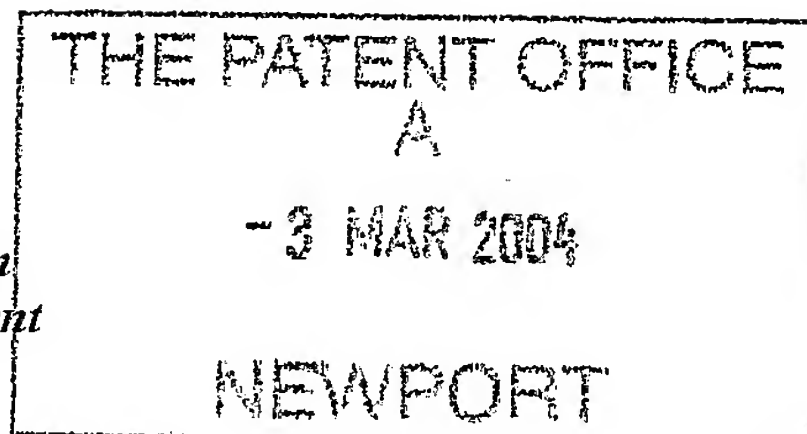
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3.	Full name, address and postcode of the or of each applicant ( <i>underline all surnames</i> )	<p>KONINKLIJKE PHILIPS ELECTRONICS N.V. GROENEWOUDSEWEG 1 5621 BA EINDHOVEN THE NETHERLANDS 07419294001</p>	
	Patents ADP Number ( <i>if you know it</i> )		
	If the applicant is a corporate body, give the country/state of its incorporation	THE NETHERLANDS	
4.	Title of the invention	TRENCH FIELD EFFECT TRANSISTOR AND METHOD OF MAKING IT	
5.	Name of your agent ( <i>if you have one</i> )		
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## DESCRIPTION

## TRENCH FIELD EFFECT TRANSISTOR AND METHOD OF MAKING IT

5           The invention relates to a trench field effect transistor (trench-FET) and to a method of making it.

          An example of a prior art trench semiconductor structure is illustrated in Figure 1. An n-type drain layer 4 is provided over an n+ substrate 2, and a p-type body layer 20 is provided on the drain layer 4. A trench 6 extends  
10       through the body layer 20 as far as the drain layer 4, and includes a conductive gate 10 insulated from the body layer by a gate insulator 9. N+ source diffusions 14 are provided adjacent to the trench. Gate electrode 26 connects to the gate 10, source electrode 22 connects to the source 14 and  
15       body 20 and drain electrode 24 connects to the substrate 2.

          In use, a voltage is applied to the gate electrode 26 to control a channel extending in the body layer 20 adjacent to the trench 6 between the source 14 and drain 4.

          A reduction of the cell pitch, i.e. the distance between adjacent cells, of  
20       a trench-FET is generally desirable, as the lower the cell pitch the greater the channel width for a fixed area of silicon. Thus, the specific on-resistance, i.e. the resistance of the FET when switched on per unit area, may be reduced by lowering the cell pitch.

          The reduction in cell pitch requires a reduction in the width of either the  
25       trench region, containing the gate, and/or the mesa region, i.e. the region with implanted source and body regions.

          Recently, a reduction in mesa width has been obtained by a blanket source implantation. In the schematic of Figure 1 above, both the body region and the source region are exposed at the first major surface. In the technique  
30       of blanket source implantation, the source region is implanted over the whole of the mesa at the first major surface leaving the body below the source

region. Since it is no longer necessary to have both source and body at the first major surface of the mesa, the mesa width can be reduced.

The downside of this approach is that it is still necessary to contact the body. This is achieved by a moat etch through the source region to the body region and a highly doped contact implant in the body region to provide a contact to the body region at the base of the moat etch. If the contact implant were to diffuse to the channel the device would become hard to turn on. It is therefore necessary that the moat is spaced away from the channel by some distance. Thus, there are limits to how far the cell pitch can be reduced using this approach.

There thus remains a need to reduce the cell pitch of trench-FET structures.

According to the invention, there is provided a trench field effect transistor (trench-FET) comprising:

- a semiconductor body having opposed first and second major surfaces;
- a source metallisation at the first major surface;
- source contact regions of semiconductor doped to have a first conductivity type at the first major surface in contact with the source metallisation;

- body contact regions of semiconductor doped to have a second conductivity type opposite to the first conductivity type at the first major surface in contact with the source metallisation;

- a drain region of first conductivity type under the first major surface;
- a drain contact connected to the drain region; and

- insulated gates including a conductive gate in an insulated trench for controlling current flow between the source contact region and the drain region through mesa regions between the insulated gates,

- wherein the source contact regions and base contact regions alternate laterally across the first major surface, with the source contact regions arranged in the insulated trench above the insulated gate.



By providing the source regions above the insulated gate the cell pitch can be substantially reduced.

For example, in preferred embodiments of the invention the cell pitch can be reduced below 1 micron. Pitches below 0.5 micron may be achieved.

5 Preferably, the mesa regions comprise doped body regions of semiconductor doped to have the second conductivity type extending under the body contact region to the drain region, the doped body regions having a lower doping density than the body contact regions.

10 The source contact region may extend to a greater depth than the base contact region so that the source contact region is in direct contact with the doped body region under the body contact region. This means that current can flow from the source contact region through the doped body region past the insulated gate to the drain region.

15 In embodiments, the first conductivity type is n-type and the second conductivity type p-type, the p-type doping of the body contact region being above  $5 \times 10^{18} \text{ cm}^{-3}$ , the p-type doping of the body region being in the range  $10^{17} \text{ cm}^{-3}$  to  $10^{18} \text{ cm}^{-3}$ , and the doping of the n-type source contact region being above  $10^{19} \text{ cm}^{-3}$ .

20 The drain region may include a drift region of lower doping above a highly doped drain region of higher doping than the drift region, both drain and drift regions being of the first conductivity type.

25 The doping in the drift region may be below  $10^{17} \text{ cm}^{-3}$ , preferably below  $5 \times 10^{16} \text{ cm}^{-3}$ , although the exact value will depend on the properties required and especially the breakdown voltage. The doping in the highly doped drain region may be above  $10^{18} \text{ cm}^{-3}$ , and is preferably highly conducting with a doping density above  $10^{19} \text{ cm}^{-3}$ , to reduce the overall resistance of the device.

The drift region may be formed as an epitaxial layer on a highly doped substrate forming the highly doped drain region. Alternatively the drift region and/or drain regions may be formed by implanting dopants.

30 It is not necessary that the source contact regions are confined to the trenches and the source contact regions may extend laterally outside the confines of the trenches as well as above the insulated gate so that the width

of the body contact regions between the source contact regions is narrower than the width of the mesa regions between the trenches. This can reduce the effects of current crowding at the top corner of the insulated gates. Such source contact regions extending outside the confines of the trench may be made simply by annealing the structure to allow the dopants in the source contact region to diffuse outwards, so such a structure is not difficult to manufacture.

In another aspect, the invention relates to a method of manufacturing a trench-FET, including the steps of:

10 providing a semiconductor having opposed first and second major surfaces doped to be of first conductivity type to form a drain region;

implanting a body contact region at the first major surface of semiconductor doped to be of a second conductivity type opposite to the first conductivity type;

15 forming trenches laterally across the first major surface alternating laterally with the body contact regions, the trenches extending below the body contact regions defining mesa regions below the body contact regions between the trenches;

forming insulated gates in the trenches;

20 depositing source regions of semiconductor doped to be of the first conductivity type in the trenches above the insulated gates; and

depositing a source metallisation at the first major surface contacting the source regions and the body contact regions.

It is of particular benefit that the body contact region may be formed by implantation at the whole of the first major surface since the unwanted doping will be removed when forming the trenches.

The method may include the step of implanting body regions of second conductivity type to a first depth greater than the depth of the source contact regions wherein the body contact implantation is carried out to a second depth less than the depth of the source contact regions so that the body contact region lies above the body regions in the finished FET.



The step of forming insulating gates in the trenches may include the steps of forming insulator on the sidewalls and base of the trenches, forming gate conductor in the trenches to a depth below the top of the trenches and forming gate-source insulator in the trenches above the gate conductor.

5

For a better understanding of the invention, embodiments will be described with reference to the accompanying drawings in which:

Figure 1 illustrates a prior art trench-FET;

Figure 2 illustrates a first step in a process according to a first  
10 embodiment of the invention;

Figure 3 illustrates the trench FET according to the first embodiment;

Figure 4 shows a simulated doping profile for the first embodiment; and

Figure 5 shows the current with the device switched off as a function of  
source-drain voltage; and

15 Figure 6 shows simulated specific  $R_{\text{dson}}$  values for the first  
embodiment.

Note that the Figures are schematic and not to scale and that like or  
similar components are shown with the same reference numeral in different  
Figures.

20

The manufacture of the device is largely conventional except for the  
filled trenches. Figure 2 illustrates a step in the manufacture of one of these  
trenches.

To form the trenches 6, a mask, conveniently of photoresist, is  
25 patterned and the epilayer 4 etched to define trenches 6 extending through  
epilayer 4 towards substrate 2. Insulator is formed on the sidewalls 9 and  
base 8 of the trenches 6 and gate polysilicon 10 deposited in the trenches 6  
and doped. Next, the gate polysilicon 10 is etched down below the top of the  
substrate to the required depth in the trench. The mask is then removed.

30 A nitride layer 30 is deposited over the whole surface to a thickness of  
30nm to 100nm. Next, a spacer etch is performed which removes the nitride

from all surfaces except the sidewalls arriving at the structure shown in Figure 2.

A wet oxidation step is carried out to grow oxide on the polysilicon gate region.

5       Next, hot phosphoric acid is used to etch away the nitride. Phosphoric acid selectively etches nitride and does not etch oxide.

Polysilicon is deposited in the top of the trench, and doped with arsenic to a doping density of  $1 \times 10^{21} \text{ cm}^{-3}$  to form source regions 14.

10       Subsequent processing follows standard processes to arrive at the finished structure of Figure 3.

It is a particular benefit of the method that the implants to form both the body region 20 and the body contact region 18 can be made over the whole of the surface unlike the contact to the body formed in a prior art structure using a moat etch, in which prior art structure the body contact implant needs to be  
15       kept away from the channel.

In the finished device, as shown in Figure 3, highly doped n+ substrate 2 forms the drain and epilayer 4 forms the drift region. The epi-layer is doped  $3 \times 10^{16} \text{ cm}^{-3}$  n-type.

20       Trenches 6 extend from the first major surface into epilayer 4. The trenches 6 include a thick trench base insulator 8 on the base of the trench, gate insulator 9 on the sidewalls of the trench 6, a conductive gate electrode 10, in the example of doped polysilicon filling the trench, and a gate-source insulator 12 above the gate electrode 10. Source region 14 of n+-doped semiconductor fills the top of the trench to a depth of 0.3  $\mu\text{m}$ .

25       Mesa region 16 between the trenches includes a body contact region 18 at the top surface heavily doped p+, in the example  $2 \times 10^{19} \text{ cm}^{-3}$ , extending to a depth of 0.25 micron. Below the body contact region 18 is the body region 20, extending to meet the drain region 4 between the trenches. The slightly shallower depth of the body contact region 18 than the source region 14 helps  
30       reduce the current crowding at the top corner of the insulated gate 10.

Source contact 22 extends along the top of the first major surface contacting the source regions 14 and body contact regions 18. The source

regions 14 and body contact regions 18 are arranged in stripes across the surface extending in the direction into the paper in Figure 3.

A drain contact 24 contacts the rear of the substrate 2. As will be appreciated, in alternative embodiments a highly doped epi-layer 4 can be used and contact made directly to the epilayer.

Figure 4 shows the doping profile in the mesa region measured from the top surface.

Figure 5 shows the current with the device switched off with 1.5V applied to the gate as a function of applied drain-source voltage. Breakdown at 29.5 V can be clearly seen.

Figure 6 shows the specific on-resistance  $R_{\text{dson}}$  with the device turned on at a number of gate voltages. With a gate voltage of 10V the specific on-resistance is  $6.2\text{m}\Omega.\text{mm}^2$  from the device of which the substrate makes a contribution of  $3.6\text{m}\Omega.\text{mm}^2$ . Thus the device has a very low specific on-resistance.

This is achieved using a very simple structure which importantly is easy to manufacture with very small cell pitch.

The skilled person will appreciate that a number of modifications may be made to the embodiments without departing from the scope of the invention. In particular, the n- and p- type regions may be interchanged.

The invention is not just applicable to silicon as the semiconductor but may be applied in any suitable semiconductor including for example GaAs. Further, the device is of simple form and may be used not merely on a single crystal substrate but also as part of thin film transistors.

From reading the present disclosure, other variations and modifications will be apparent to persons skilled in the art. Such variations and modifications may involve equivalent and other features which are already known in the design, manufacture and use of more boilerplate and which may be used in addition to or instead of features described herein. Although claims have been formulated in this application to particular combinations of features, it should be understood that the scope of disclosure also includes any novel feature or any novel combination of features disclosed herein either explicitly or implicitly

or any generalisation thereof, whether or not it mitigates any or all of the same technical problems as does the present invention. The applicants hereby give notice that new claims may be formulated to any such features and/or combinations of such features during the prosecution of the present  
5 application or of any further applications derived therefrom.

## CLAIMS

1. A trench field effect transistor (trench-FET) comprising:
  - a semiconductor body having opposed first and second major surfaces;
  - 5 a source metallisation (22) at the first major surface;
  - source contact regions (14) of semiconductor doped to have a first conductivity type at the first major surface in contact with the source metallisation (22);
  - body contact regions (18) of semiconductor doped to have a second
  - 10 conductivity type opposite to the first conductivity type at the first major surface in contact with the source metallisation;
  - a drain region (2,4) of first conductivity type under the first major surface;
  - a drain contact (24) connected to the drain region; and
  - 15 insulated gates (10) including a conductive gate (10) in an insulated trench (6) for controlling current flow between the source contact region (14) and the drain region (2,4) through mesa regions (16) between the insulated gates,
  - wherein the source contact regions (14) and base contact regions (18)
  - 20 alternate laterally across the first major surface, with the source contact region arranged in the insulated trench (6) above the insulated gate.
2. A trench-FET according to claim 1 wherein the mesa regions comprise doped body regions (20) of semiconductor doped to have the second
- 25 conductivity type extending under the body contact regions (18) to the drain region (2,4), the doped body regions (20) having a lower doping density than the body contact regions.
3. A trench-FET according to claim 2 wherein the source contact
- 30 regions (14) extend to a greater depth than the base contact regions (18) so that the source contact regions (14) are in direct contact with the doped body regions (20) under the body contact regions (18) so that current can flow from



the source contact regions (14) through the doped body regions (20) past the insulated gate (10) to the drain regions (2,4).

4. A trench-FET according to claim 2 or 3 wherein the first conductivity type is n-type and the second conductivity type p-type, the p-type doping of the body contact region being above  $5 \times 10^{18} \text{ cm}^{-3}$ , the p-type doping of the body region being in the range  $10^{17} \text{ cm}^{-3}$  to  $10^{18} \text{ cm}^{-3}$ , and the doping of the n-type source contact region being above  $10^{19} \text{ cm}^{-3}$ .

5. A trench-FET according to any preceding claim wherein the drain regions include a drift region (4) of lower doping above a highly doped drain region (2) of higher doping than the drift region, both drain and drift regions being of the first conductivity type.

6. A trench-FET according to claim 5 wherein the doping in the drift region (4) is below  $10^{17} \text{ cm}^{-3}$  and the doping in the highly doped drain region (2) is above  $10^{18} \text{ cm}^{-3}$ .

7. A trench-FET according to any preceding claim wherein the source contact regions (14) extend laterally outside the confines of the trenches (6) as well as above the insulated gate (10) so that the width of the body contact regions (22) between the source contact regions (14) is narrower than the width of the mesa regions between the trenches.

8. A method of manufacturing a trench-FET, including the steps of:  
providing a semiconductor body (2,4) having opposed first and second major surfaces doped to be of first conductivity type to form a drain region;  
implanting a body contact region (18) at the first major surface of semiconductor doped to be of a second conductivity type opposite to the first conductivity type;  
forming trenches (6) laterally across the first major surface alternating laterally with the body contact regions (18), the trenches extending below the

body contact regions (18) defining mesa regions below the body contact regions (18) between the trenches (6);

forming insulated gates (10) in the trenches (6);

depositing source regions (14) of semiconductor doped to be of the first conductivity type in the trenches (6) above the insulated gates (10); and

depositing a source metallisation (22) at the first major surface contacting the source regions (14) and the body contact regions (18).

9. A method according to claim 8 further comprising the step of implanting body regions (20) of second conductivity type to a first depth greater than the depth of the source contact regions (14) wherein the body contact implantation (18) is carried out to a second depth less than the first depth.

10. A method according to claim 8 or 9 wherein the step of forming insulating gates (10) in the trenches includes the steps of forming insulator (8,9) on the sidewalls and base of the trenches (6), forming gate conductor (10) in the trenches (6) to a depth below the top of the trenches and forming gate-source insulator (12) in the trenches above the gate conductor (10).

11. A trench-FET substantially as described herein with reference to figures 2 to 6 of the accompanying Drawings.

12. A method of manufacturing a trench-FET substantially as described herein with reference to figures 2 to 6 of the accompanying Drawings.

**ABSTRACT****TRENCH FIELD EFFECT TRANSISTOR AND METHOD OF MAKING IT**

5 A trench-FET has source regions arranged above insulated gates 10 in  
trenches 6. Body region 20 of opposite conductivity type is arranged between  
the trenches 6 and body contact region 18 is arranged above the body region  
20. Source contact metallisation 22 contacts the source 14 and body contact  
region 20. In this way a small cell pitch can be achieved.

10

[Fig 3]

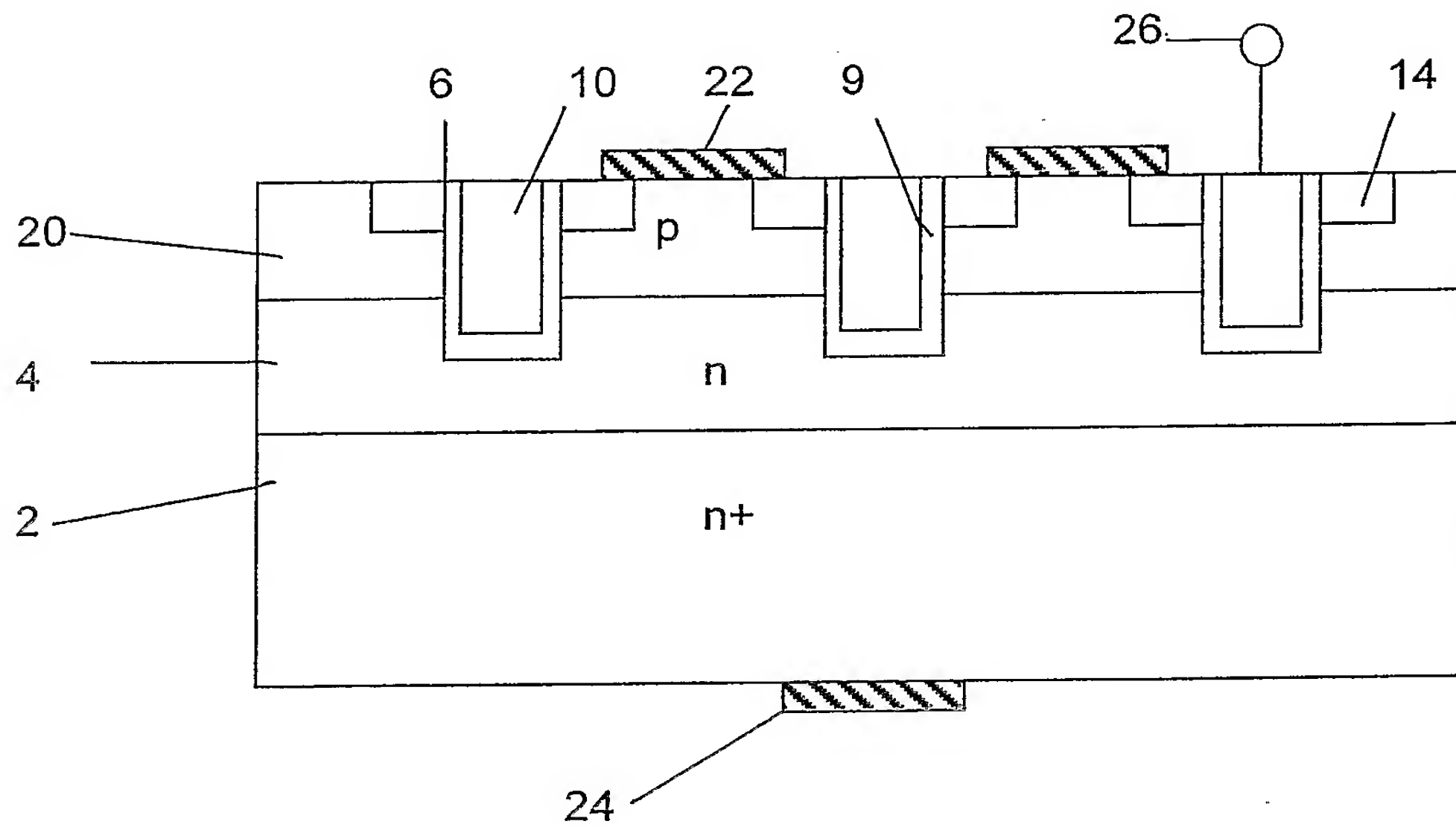


Fig. 1

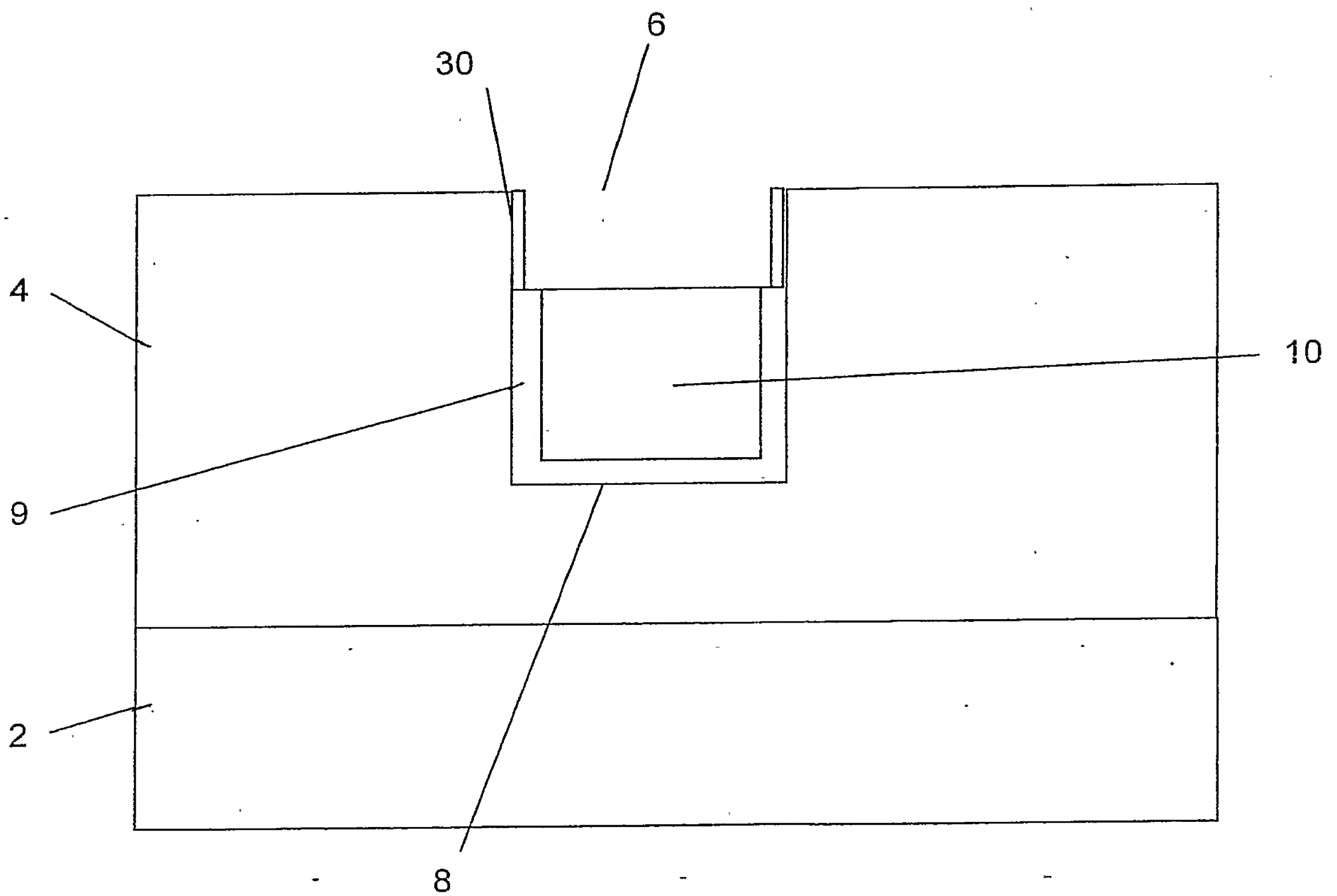


Fig. 2





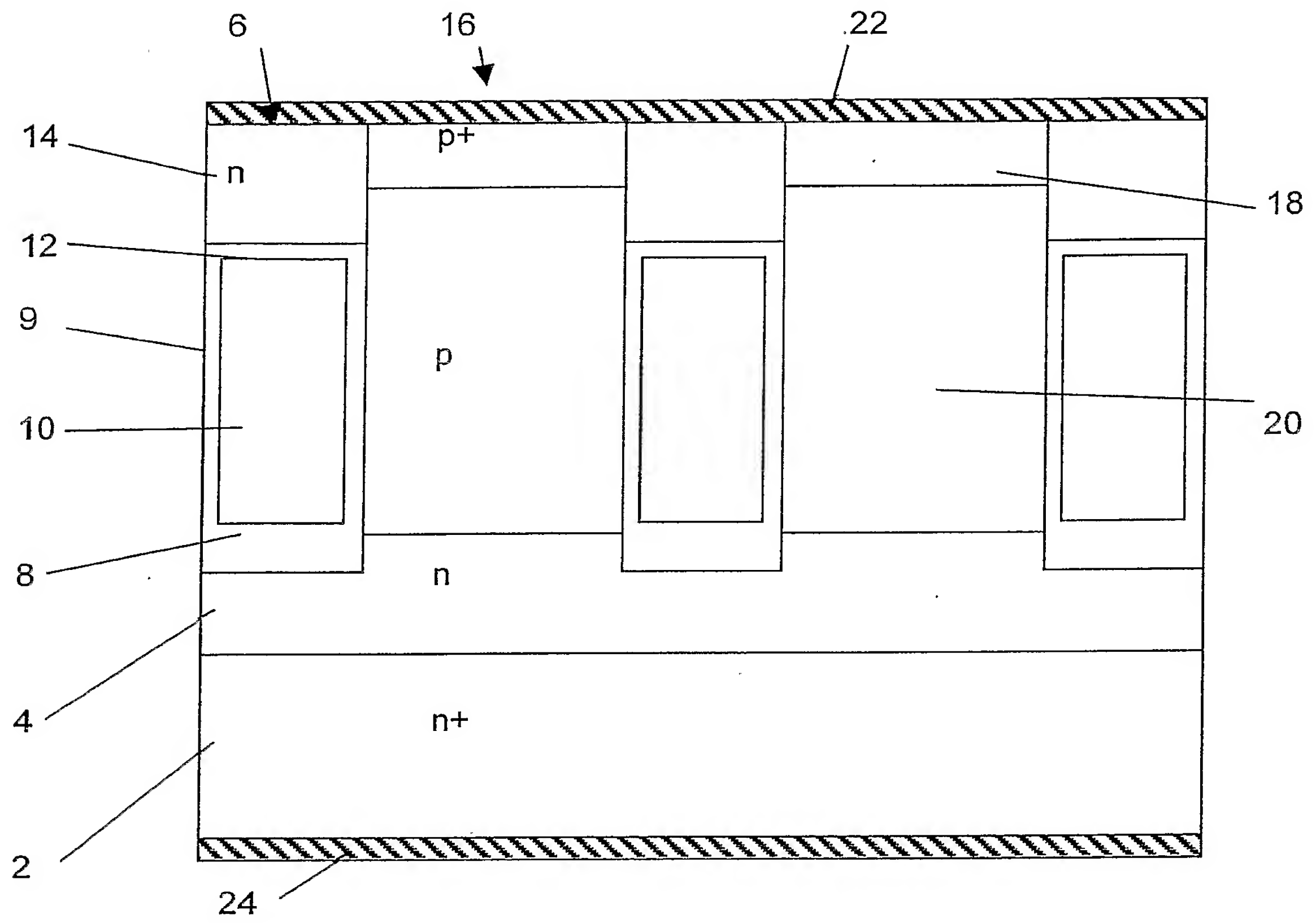
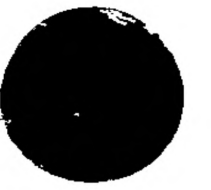


Fig. 3



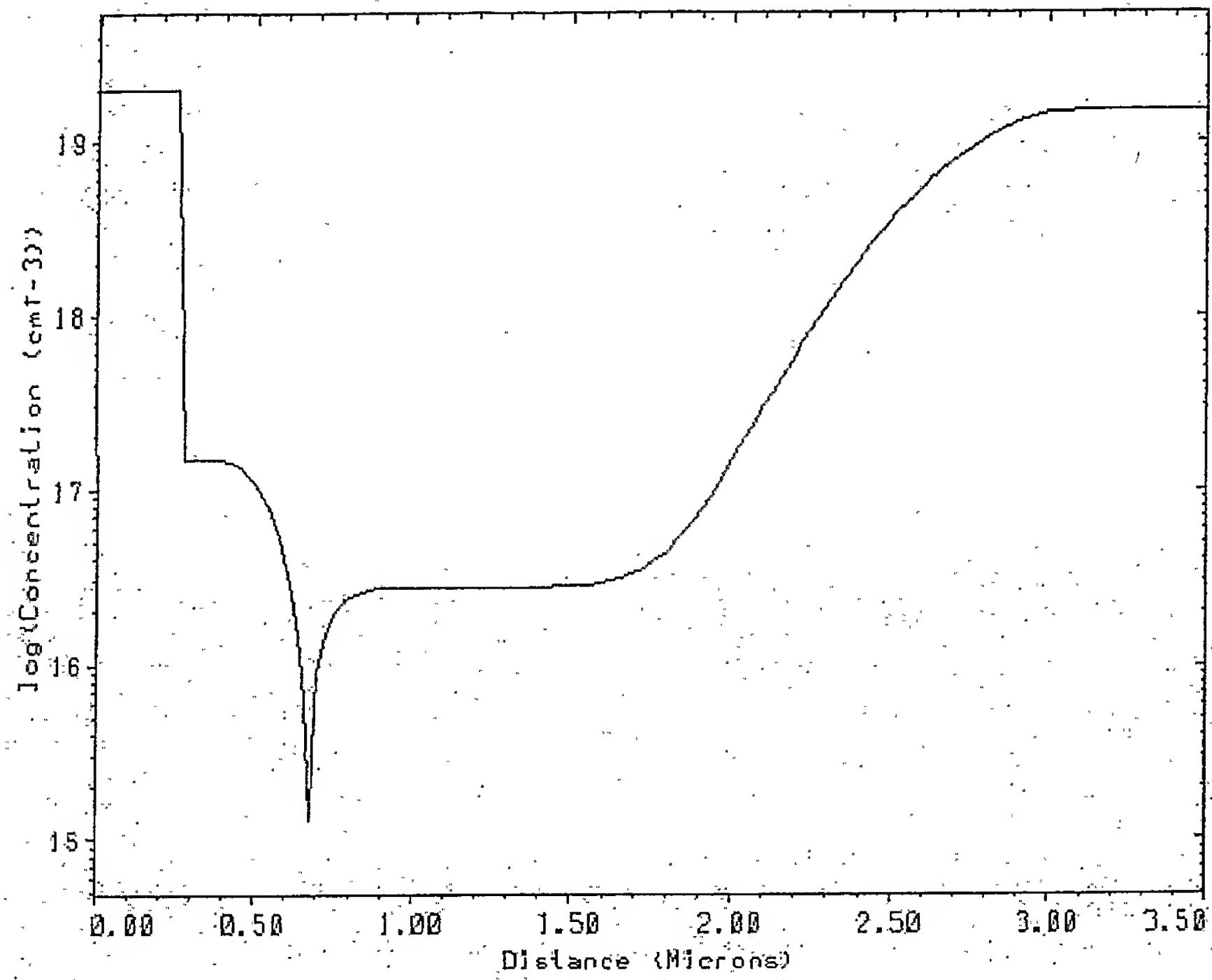


Fig.4

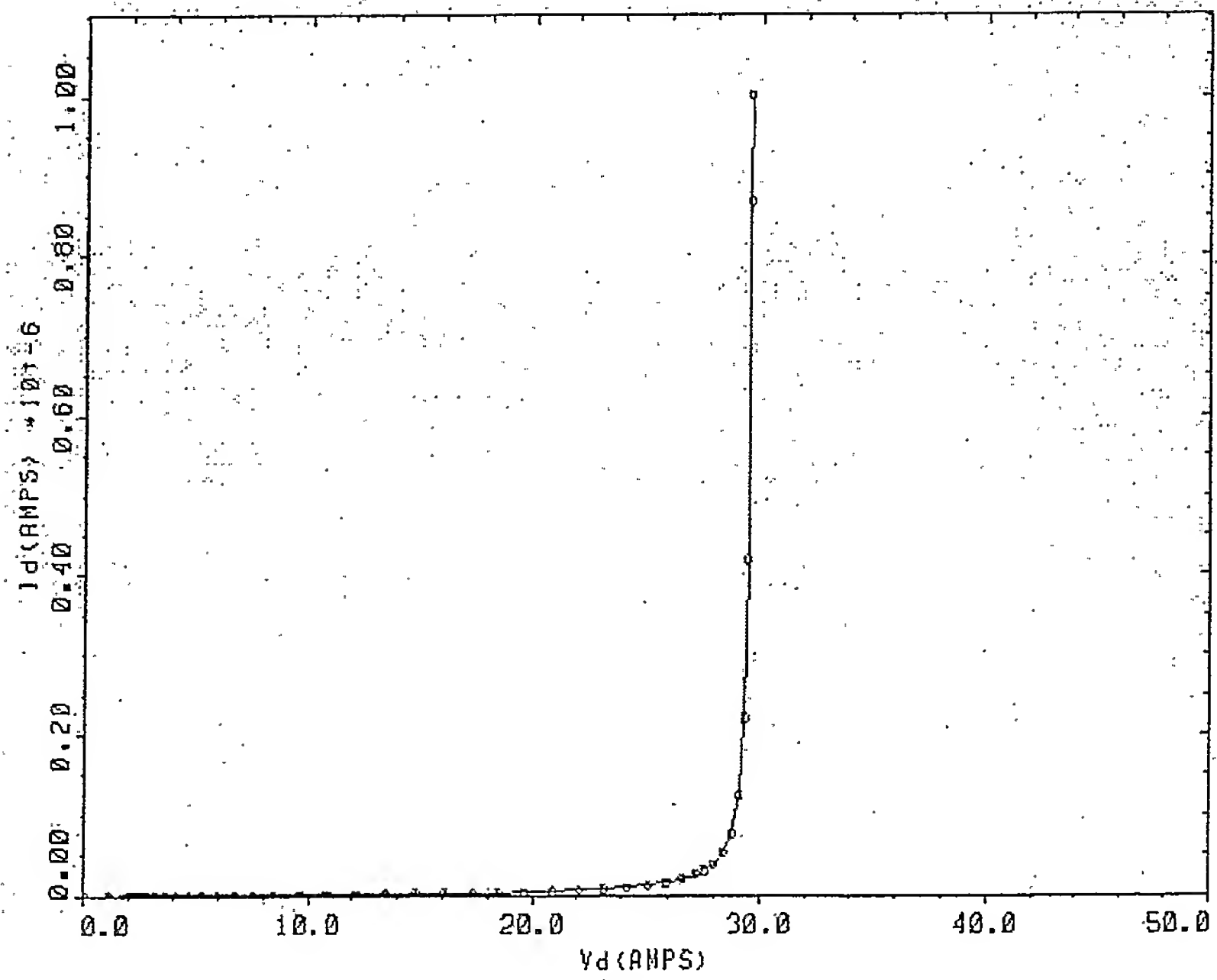


Fig.5



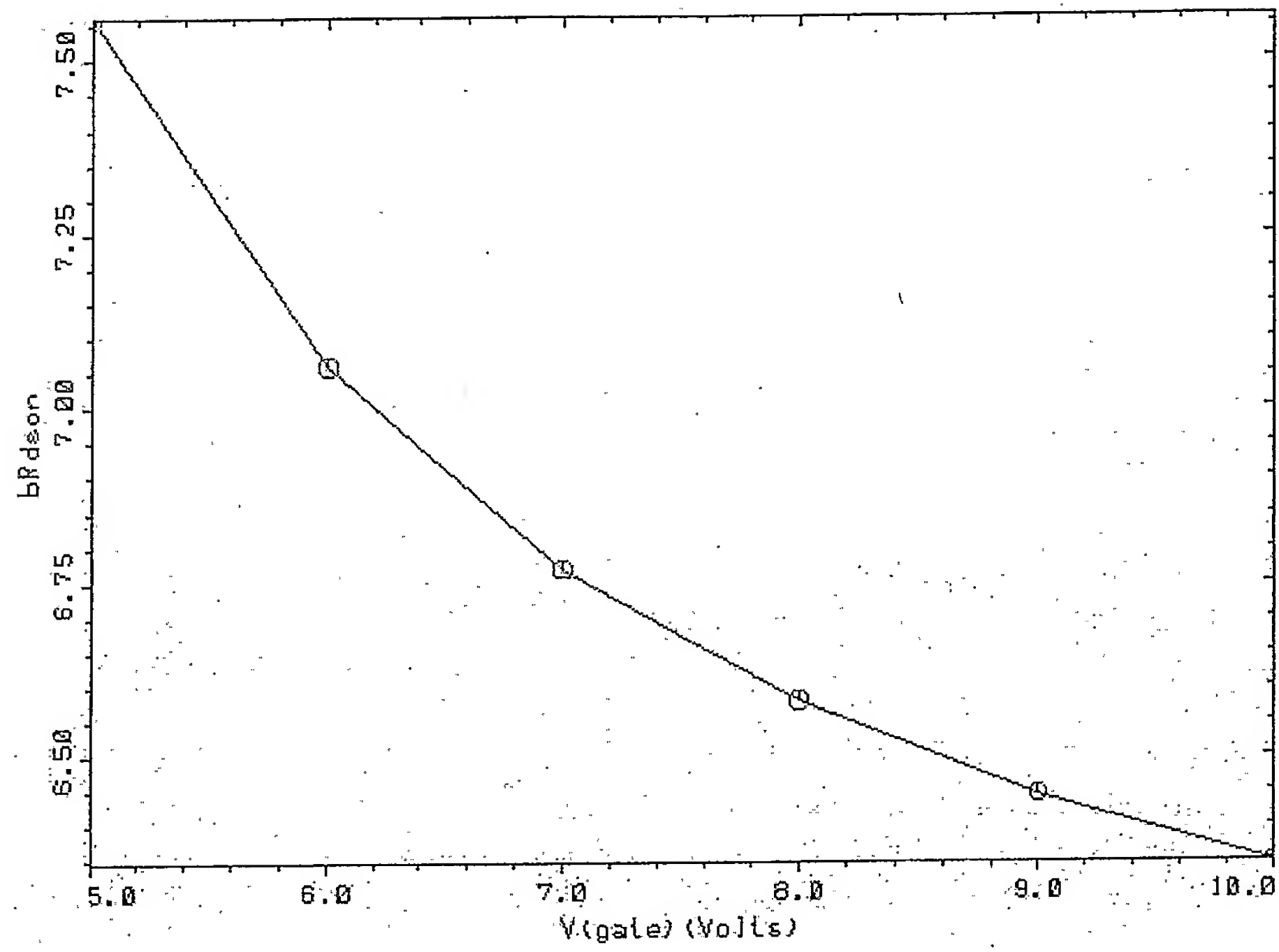


Fig. 6



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